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## ANTI-REFLECTION COATINGS

ON

## LARGE AREA GLASS SHEETS

QUARTERLY TECHNICAL REPORT NO. 3  
MOTOROLA REPORT NO. 2366/3  
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1 JULY 1979 - 30 SEPTEMBER 1979

JPL CONTRACT NO. 955339

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THE JPL LOW-COST SOLAR ARRAY PROJECT IS SPONSORED BY THE U.S. DEPARTMENT OF ENERGY AND FORMS PART OF THE SOLAR PHOTOVOLTAIC CONVERSION PROGRAM TO INITIATE A MAJOR EFFORT TOWARD THE DEVELOPMENT OF LOW-COST SOLAR ARRAYS. THIS WORK WAS PERFORMED FOR THE JET PROPULSION LABORATORY, CALIFORNIA INSTITUTE OF TECHNOLOGY BY AGREEMENT BETWEEN NASA AND DOE.

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## 1.0 SUMMARY STATEMENT

This is the third quarterly report of a one year program designed to research and perfect a method of producing antireflective coatings on large glass sheets through the use of sodium silicate hardened by exposure to acid.

The linear motion device required for precise study of the filming technique has been completed and is now in use. Some difficulty in obtaining parts for the device made the use of substitute equipment necessary, causing delays in the production of film samples. These delays are minor and will not seriously effect completion of the program.

Tasks 1, 2, and 3 - Construct Linear Drive, Prepare Sodium Silicate Solutions, and Determine Solution Physical Properties - have been completed. All other tasks are in progress except Task 8 - Prepare Demonstration Samples. This task will be addressed later in the program as scheduled.

## 2.0 INTRODUCTION

The ultimate goal of this project is improvement of the efficiency of photovoltaic modules through increased transmission of light by the module cover. One method of increasing transmission is by reducing the reflection of light by the module cover, a reflection which accounts for a 4% loss of transmission for each coverglass-air interface.

This study is intended to advance a known antireflection technology to the point where large area glass module covers can be treated to produce uniform, efficient, and durable antireflective films.

### 3.0 TECHNICAL DISCUSSION

#### 3.1 SPECIFIC AREAS OF PROGRESS

As noted in the last quarterly, dust and carbon dioxide present in the atmosphere during film formation have undesirable effects on the performance of silicate AR films. Experiments performed during the last quarter have clarified the extent of these problems and have yielded solutions to them.

##### 3.1.1 DUST CONTROL

Dust which is incorporated into the film during its formation from a liquid layer causes unevenness in the thickness of the layer leading to variations in the wavelengths of light for which reflection is reduced. In addition, dust may be intrinsically opaque or become so after exposure to the sulfuric acid used in hardening the film and thus cause a reduction of transmitted light by absorption.

Filtration of the air surrounding the filming apparatus has been used in an effort to remove airborne dust. The early attempts at filtration used spongy plastic filters similar to those used in room air conditioners, and later cloth and paper filters of finer mesh were employed. All of these filters proved unsatisfactory, the plastic sponge filter was far too porous to catch all but the largest dust particles, while the cloth and paper filters merely replaced the dust originally in the air with fibers from themselves. At this point it was decided to test one of the gas filters available commercially. A non-shedding cartridge filter - Pall 0.35 micron Ultipore DFA-UFA Disposable Filter Assembly - was tested and found satisfactory at removing all detectable dust from the gas surrounding the filming glass.

### 3.1.2 CARBON DIOXIDE CONTROL

Carbon dioxide present in the air will react with a film of dried sodium silicate to cause a cloudy product containing particles of sodium carbonate and precipitated silica. Such a reaction occurs only when the sodium silicate film is exposed to the atmosphere for very long periods of time - in excess of 24 hours. It is expected that silicate AR films produced commercially will receive a sulfuric acid dip (which renders them unreactive) long before the carbon dioxide-caused clouding occurs. There is however, a high probability of the sodium silicate filming mixture reacting with atmospheric  $\text{CO}_2$  and clouding, becoming unsuitable for film production. For this reason it has been found advantageous to enclose the filming apparatus in an atmosphere of filtered dry nitrogen, rather than air. In this nitrogen atmosphere, silicate solutions that would have clouded in only one day in air remained clear indefinitely.

### 3.1.3 HUMIDITY EFFECTS AND CONTROL

Humidity of the nitrogen atmosphere around the filming glass had unexpectedly few effects on the film formation process. It was originally thought that the introduction of nitrogen of a controlled humidity to the chamber in which filming is conducted would promote the formation of unusually smooth films (by delaying drying long enough to allow the fluid to level itself on the glass) or allow fine control of film thickness (again by delaying drying long enough to allow additional draining of filming fluid from the glass surface). In contrast to the expected results, humidification resulted in uneven films and increased dust contamination of films.

Experiments were conducted by bubbling nitrogen through water at various temperatures before admitting the  $\text{N}_2$  into the filming chamber. At all levels



of humidification, the moist nitrogen delayed drying of the film drastically - long enough for the wet film to catch the few dust particles that enter the chamber from the outside when glass is inserted into the chamber, and also long enough for air currents to disturb the liquid film and cause it to become uneven. Additionally, the drying process itself took much longer than was convenient for efficient production. The hygroscopic nature of sodium silicate contributed to the problem by selectively absorbing moisture from the atmosphere and multiplying the effect of even slight humidity.

In view of the results of these experiments, it was found that dry  $N_2$  provides the atmosphere most conducive to reproducible film formation. In the system, granular potassium hydroxide is employed as a desiccant, and is placed in an open vessel directly in the chamber rather than in the incoming  $N_2$  line. This arrangement permits the desiccant to remove moisture generated by evaporation from the filmed sheets, the filming solution reservoir itself, and that moisture admitted by opening the chamber to insert glass samples.

#### 3.1.4 FILMING APPARATUS CONFIGURATION

The results of the experiments conducted and described above have permitted the specification of the conditions under which filming is most easily conducted. The filming apparatus has been modified to these specifications and is as follows.

A large 30 cm cube composed of plexiglas serves as the filming chamber. In one wall of the chamber is an 18 cm square door (without gaskets) and an 1/8 inch gas port at the lower rear of the chamber admits dry  $N_2$  gas which has been filtered through a Pall 0.35 micron Ultipore DFA-UFA Disposable Filter Assembly. The gas flow rate is 5-10 l/minute. The gas flow is sufficient to create a positive pressure in the chamber, preventing the entrance of outside atmosphere. At the same time,

the flow is gentle enough to avoid causing strong gas currents that would disrupt the liquid film formed on the glass. A small pan containing granular KOH or NaOH is placed near the gas inlet port. In the chamber is placed a container of sodium silicate filming solution. A small hole in the top of the chamber is provided to accomodate a heavy nylon cord with a clamp attached to the end. The cord and clamp are positioned over the container of sodium silicate and serve to withdraw glass sheets vertically from the solution at constant-speed. The nylon cord is driven by a constant speed drive which is mounted externally. The filming procedure is conducted at ambient temperature.

#### 3.1.5 ABRASION TESTING

The abrasion resistance of filmed glass samples was evaluated. Samples of glass were filmed by drawing them at 5.62 cm/min. from a 10% by volume solution of Humco sodium silicate solution in deionized water. The plates were then allowed to dry in the N<sub>2</sub> atmosphere. After drying, the plates were exposed to 96+% sulfuric acid for two minutes, followed by a ten minute deionized water rinse, after which the plates were wiped dry with paper towels.

Abrasion was performed in two ways: without abrasive by a cotton pad, and with the same cotton pad loaded with abrasive powder. The pad was composed of 4 layers of 0.008 inch cotton duck, with a circular area of 13.9 cm<sup>2</sup>. The pad was loaded with weights to yield a pressure of 138 g/cm<sup>2</sup>. After conducting abrasion tests with the pad alone on five samples of filmed glass, the pad was stamped in Buehler No 40-6475 AB, 3200 mesh abrasive, then tapped to remove adhering clumps of abrasive so that only the abrasive that had been worked into the cloth was available. The abrasive on the pad was renewed for each of the five samples tested. The testing was performed by moving the pad laterally across the filmed glass surface in 2 inch strokes, with visual inspection of the glass after every 5 strokes. Below is summarized the result of the tests.

ABRASIVE	EFFECT	STROKES REQUIRED
Cloth Only	First sign of damage	> 200
	Moderate Wear	---
Cloth Plus Abrasive Powder	First sign of damage	100
	Moderate Wear	300
	Film Removed	> 500

As shown above, the films produced by the silicate process are especially rugged. With cloth alone, over 200 strokes were required to cause any sign of damage to the film. The "over" designation was used because of the ambiguous appearance of damaged film. No easily identified scratches or other marks appeared, but rather, a gradual change in film color that was difficult to detect visually. Moderate wear was defined as unmistakable damage covering the entire stroked area but not resulting in complete removal of film from any area. Without abrasive, it was impossible to produce this kind of damage.

With the abrasive, endurance of the films was still remarkable. Complete removal of film was not accomplished, the 500 strokes listed represents removal of 95% of the film in the stroked area.

#### 4.0 PROJECTED ACTIVITIES FOR THE NEXT THREE MONTHS

Production of antireflective film on 4 inch square glass plates will continue, with the use of a still nitrogen ambient atmosphere in order to produce smooth films free of carbonate.

Production of samples will be achieved with a wide range of silicate solution concentrations (10% to 50% by volume) and withdrawal speeds in order to determine the most material efficient and fastest method of production. Durability testing will be performed at the end of this series of experiments. Optical testing will begin after the full range of concentration and withdrawal speed samples are produced.

#### 5.0 RECOMMENDATIONS

No recommendations are made at this time.

#### 6.0 CURRENT PROBLEMS

No urgent problems have arisen.

#### 7.0 WORK PLAN STATUS

Work that was delayed by the date completion of the linear drive is being addressed, and no serious delays are anticipated.

#### 8.0 ACTION ITEMS

Reports are late. Efforts are under way to correct this.

#### 9.0 NEW TECHNOLOGY

No reportable items of new technology have been identified, as yet.

#### 10.0 PROGRAM AND DOCUMENTATION MILESTONES

Activities associated with the total program are shown in the Program and Documentation Milestone Charts Figures 1 and 2 contained in Appendix 1.

## APPENDIX I

MONTH

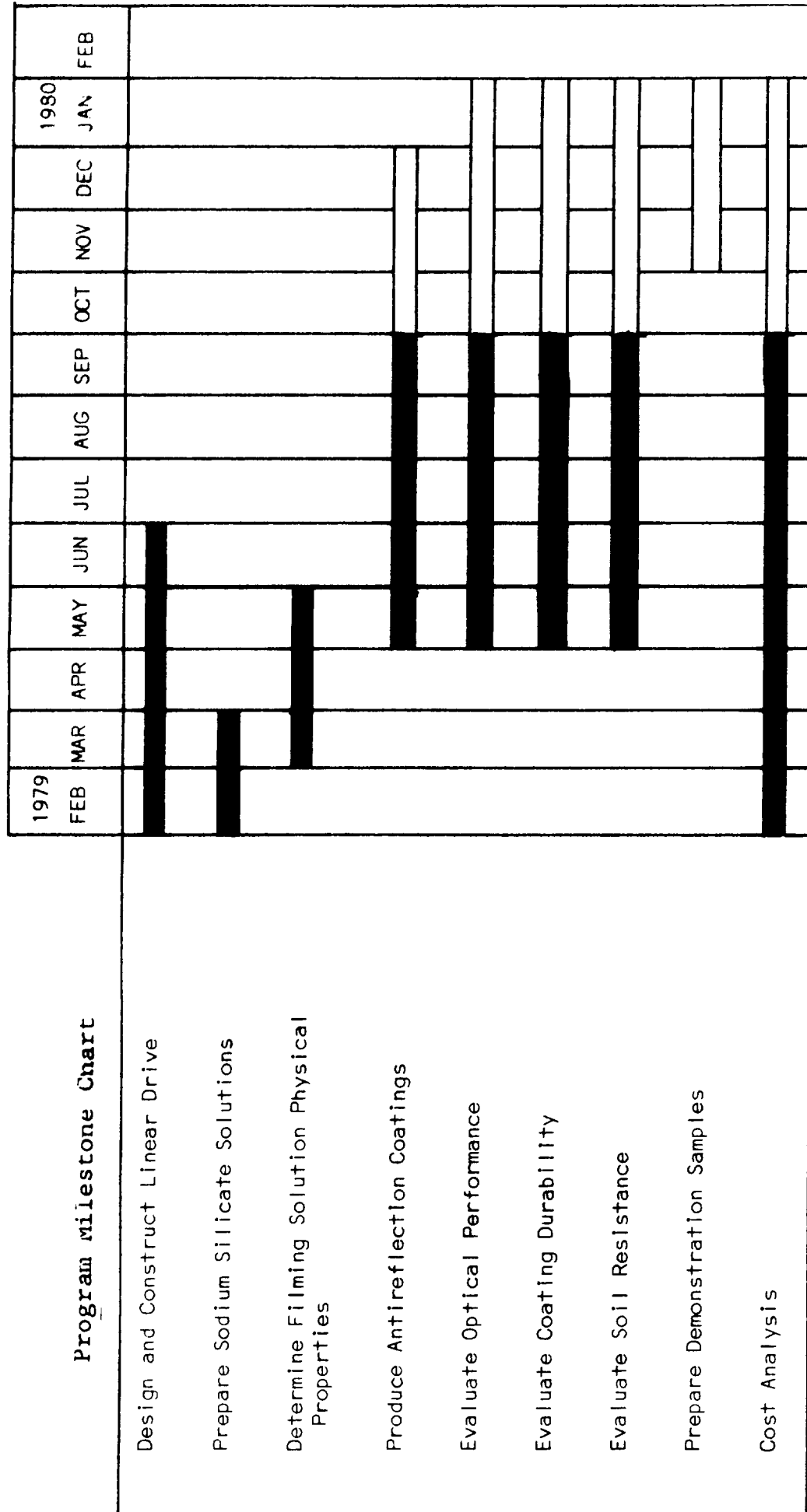


FIGURE 1

DOCUMENTATION MILESTONE CHART	MONTHS											
	1979 FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	1980 JAN
		▲	▲	▲	▲	▲	▲	▲	△	△	△	△
Monthly Financial Management Report		▲		▲	▲		▲	▲	△	△	△	△
Technical Letter Progress Report		▲		▲	▲		▲	▲		△	△	
Quarterly Technical Report		▲	▲		▲	▲		▲				
Draft Final Report												△
Final Report												△
Program Plan	▲											
Baseline Cost Estimate	▲											
Chemical/Process/Equipment Cost Analysis												△

FIGURE 2